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Xカット LiNbO$_3$を用いた光周波数シフタ/SSB-SC変調器の開発

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あらまし ニオブ酸リチウム（LN）結晶を用いて作製される、光 SSB-SC(Single Side-Band with Suppressed Carrier)変調器は、今後ますます大容量化する DWDM システムを構築する上で有用なデバイスである。以前、我々はzカット LN 結晶を利用して SSB-SC 変調器の開発を行ったが、電極構成上の理由から駆動系が複雑になる問題があった。今回、駆動系の簡略化を目的として、xカット LN を使用した SSB-SC 変調器を開発したところ、キャリア抑圧比（1次側帯波とキャリアの比）28dB と、良好な評価結果が得られたので報告する。

キーワード xカット LN、SSB-SC 変調器、キャリア抑圧比、周波数シフタ

The Development of X-cut LiNbO3 Optical Frequency Shifter / SSB-SC Modulator

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Abstract Optical SSB-SC(Single Side-Band with Suppressed Carrier) modulator using LiNbO3 crystal is a promising device to develop the future DWDM systems. Authors have developed an SSB-SC modulator using z-cut LiNbO3(LN), however the set-up for driving it is rather complex. In this study, an SSB-SC modulator using x-cut LN was newly developed. It can be driven by a simple set-up and 28dB sideband/carrier suppression ratio was achieved.

1. Introduction

Presently, expansion of capacity and coverage area of basic type network are investigated intending to satisfy the increasing demand of Internet communication. But, in a realization of the long distance transmission possible system having large capacity, there are difficult

circumstances depending upon, various physical factors such as fiber wave length dispersion and the non-linear effect. Each institution energetically has gone development of the optical parts of new modulation system and the new fiber etc, in order to overcome this limit, from the view point of enlargement of available wave length zone, increase in the non-linear effective tolerance of long distance communication, increase in the frequency utilization efficiency, and so on. Recently, the experiment which succeeds in the transmission experiment having super large capacity was reported. The experiment was supported by the development of the amplifier of the S band including expanding the wave length limits, adopting polarized wave multiplex mode. The development has made the frequency utilization efficiency redouble. But, also problems such that long distance transmission is difficult with influence of polarized wave fraction remains. You can say other than the problem that, information processing ability of the electronic device in the telecommunication network node section has become the bottleneck of large increasing capacity, there is a problem which still should be investigated from the technical aspect in future network construction.

Generally, as for frequency utilization efficiency (concerning large increasing capacity) and non-linear yield (concerning long distance) because there is a relationship of trade-off, these realization of the modulation system which can be compatible is difficult. By the way, as the carrier suppressing optical single side-band (the SSB-SC: The Single Side-Band with Suppressed Carrier) modulation system can make reduction in the spectrum width by half, from the fact that it is possible to suppress the carrier simultaneously, SSB-SC is one of the promising modulation systems which shows high frequency utilization efficiency and non-linear endurance. The authors, in the past, using the Z cutting LiNbO3 (Z-cut-LN) substrate, succeeded in the development of the optical SSB-SC modulator which has satisfactory carrier suppressing quality.

However, as the crystal orientation of the most big electro-optic

effect of the Z-cut-LN (the Z axis) is vertical to the substrate, in order to adopt the electrode distribution arrangement of symmetrical co-plainer structure, there is a necessity to arrange the signal electrode on all waveguidees surfaces. Because of that, the number of parts of the electronic circuit for drive increases, system becomes complicated, in regard to utility such that phase adjustment of the input signal becomes difficult, these inconvenient problems has raised. In this research, the SSB-SC modulator which utilizes the x-cut-LN substrate anew with the simplification of drive system as a main purpose, was developed, and the modulation efficiency were appraised for a 10GHz single tone and a 12Gb/s digital data.

Furthermore, when this modulator is modulated with single tone, as only the single sideband spectrum can remain, therefore it can be regarded as an optical frequency shifter, also we have investigated several application as the optical functional device which forms future photonic network.

2. Constitution and principle of the SSB-SC modulator

As for this modulator, as shown in figure 1, two sub MZ (Mach-Zehnder) waveguide MZa and MZb are arranged in parallel in each arm of the main MZc, it belongs to interleave type MZ structure.

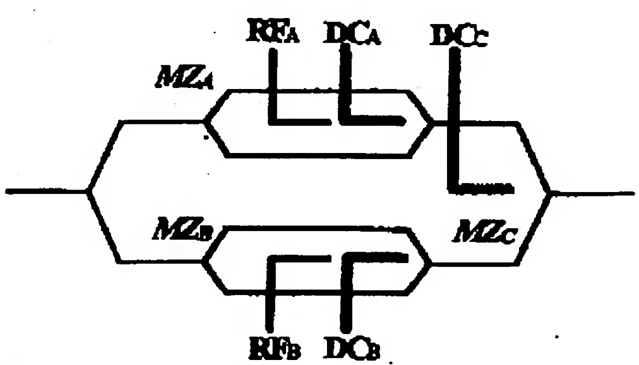


図1． x-LN光SSB-SC変調器の導波路構成

Fig.1, Waveguide of a x-LN optical SSB-SC modulator.

Originally, SSB modulation technology is the technology which is utilized in the radio communication field. It is known that the SSB modulated signal is obtained by taking the sum of the field signal and Hilbert conversion of the signal. The modulator in figure 1 shows simply how to generate SSB-SC signals. First, let exp(jωt) as incident light, a single frequency RF signal φcosΩt from the RFa port, and a H[φcosΩt]=φsinΩt which is a Hilbert conversion of this signal, are inputted simultaneously from the RFb port. Because it is sinΩt=cos (Ωt+π/2), two signals can be supplied simultaneously by utilizing the phase shifter of microwave. Here, as φ for degree of modulation, ω、Ω for angular frequency of the respective light wave and the RF signal shows respectively. Furthermore phase difference π/2 is given between the light wave outputted from both arms of the MZc including suitable bias from the DCa port. In order that simultaneously, between the light wave which outputted from both arms of the MZa and the MZb, the carrier is suppressed, when phase difference π is given, the formula which displays the light wave with the last combination wave position is displayed (as for the component the after 4th order is neglected) as;.

$$
\begin{aligned}
& e^{j\omega t}\{(e^{j\phi\cos\Omega t}+e^{-j\phi\cos\Omega t})e^{j\pi} \\
& +(e^{j\phi\sin\Omega t}+e^{-j\phi\sin\Omega t}e^{j\pi})e^{j\pi/2}\} \\
= \; & e^{j\omega t}\{J_{-3}(\phi)e^{-3j\Omega t}+J_{+1}(\phi)e^{j\Omega t}\} \qquad (1)
\end{aligned}
$$

In this case, in the each point of the waveguide, the optical spectrum component is displayed as in figure 2.

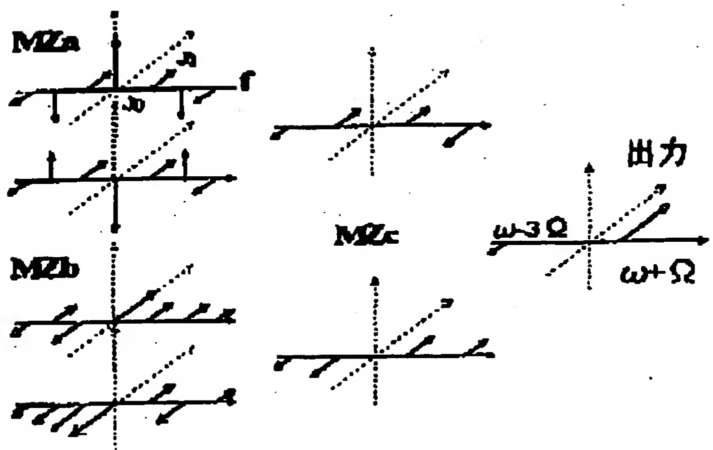


図2. 導波路各点での光スペクトル

Fig.2, Optical spectra at several point on the waveguide.

The spectrum component of -3rd order (minus means LSB) and the primary spectra remain, but the even number including 0^{th} order, and -1st order components are lost. If the -3rd order spectrum is sufficiently small, it is obtained a signal of which carrier frequency is shifted Ω.

3. Fabrication of modulator

3.1 fabrication process

Here, we describe simply concerning the production method of the modulator. First, on the x-cut-LN substrate of the thickness 1mm and diameter of 4 inches, waveguide in resist pattern is formed photo-lithographically. Next, approximately 900 Angstroms of Ti thin film was accumulated on the substrate by a metallization process, after a lift-off process, the thermal diffusion was processed under a condition of 1000 C・20 hour. After this process, corresponding to the sub MZa and MZb, the traveling-wave type co-plainer electrodes RFa and RFb, and the DC electrodes DCa and DCb in series for phase adjustment of the light wave, and corresponding to MZc, the DC electrode DCc. Each one, in

intermediate position of the arm where each MZ waveguide interferometer opposes, is produced making use of electric field Au plating method. Because of high frequency usage, the electrode was made approximately 25 um thick. The fiber is fixed on the chip both ends which are quarried out from the substrate, and is hermetically sealed, the modulator completes in the frame of the SUS303. Outline of the SSB-SC modulator is shown in figure 3.

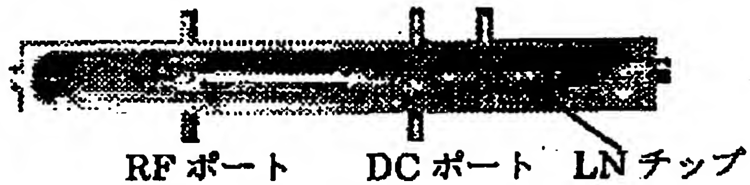


図 3. SSB-SC 変調器外観

Fig.3, Outlook of a SSB-SC modulator.

3.2, Meris of using an x-cut-LN substrate.

The DC drift is small in the x-cut-LN modulator, zero chirp, with there is a merit which was said with single drive, but speed adjustment of light and microwave is difficult, there is also a defect where drive voltage somewhat becomes high. On one hand, speed adjustment is easy in the z-cut-LN modulator, while there is a merit that, drive voltage is low, when (it is single drive) the chirp exists, there is also a defect that the DC drift is a little large. Respectively, they have advantage and disadvantage, according to, but what is seriously considered in the application field, it is used properly. This is similar concerning the SSB modulator of this report.

With former development in order to decrease the drive power, the z-cut-LN substrate has been used, but, it needs to apply the electric field of the same strength to the respective light wave which transmits four waveguide arms, accurately, at the same time unless precision well it is necessary to do phase adjustment. Unless the adjustment, because of a

variation in degree of modulation, you cannot obtain sharp one sided sideband modulation characteristic. Therefore, the signal electrode four arms have to be installed respectively. Because of that, the number of electronic parts and the connector such as amplifier and phase shifter and attenuator for input signal drive equal to amount of the signal electrode becomes necessary.

On one hand, when the x-cut-LN substrate is utilized, and as in figure 1, if the signal electrode is installed in central position of the MZ interferometer, from its symmetry, it is possible to give the electric field of the same strength to two waveguides simultaneously, with one signal electrode. This is the case of single drive and a zero-chirp. This is because the Z axial direction being parallel to the substrate surface, and because it is vertical to the waveguide traveling direction. In other words with the z-cut-LN the signal electrode (Hot electrode) which four are necessary, with the x-cut-LN 2 as for that becomes sufficiently. The x-cut-LN-SSB-SC modulator and the z-cut-LN - the SSB - the SC modulator both chip cross section diagram are shown in Figure 4.

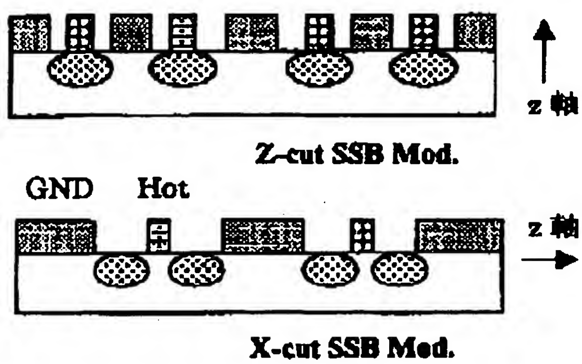


図4. x-LN SSB-SC 変調器と z-LN SSB-SC 変調器
のチップ断面図(a)z-LN (b) x-LN

Fig.4, Cross-sections of x-LN SSB-SC modulator and z-LN SSB-SC modulator, (a) z-LN, (b) x-LN.

With the x-cut-LN, amount and the number of electronic parts where the electrodes for signals are few, also adjustment place decreases, it is

understood that it can become simpler drive system.

4. Performance evaluation

4.1 10GHz single-tone (optical frequency shifter)

Actually it confronts the 10GH Z single cycle of the x-cut-LN SSB-SC modulator which was developed this time making use of the drive system which is shown in figure 5, carrier suppressing (J1/J0) and sideband suppressing (J1/J-1) quality were inspected.

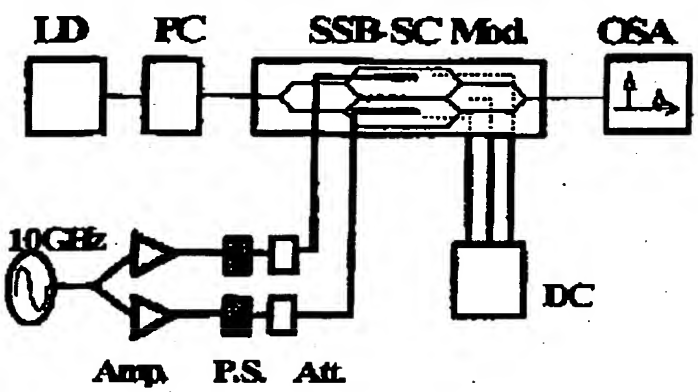
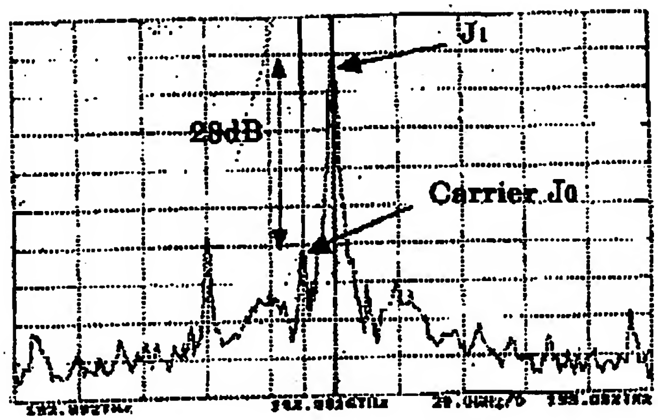


図5. 光周波数シフタ駆動系

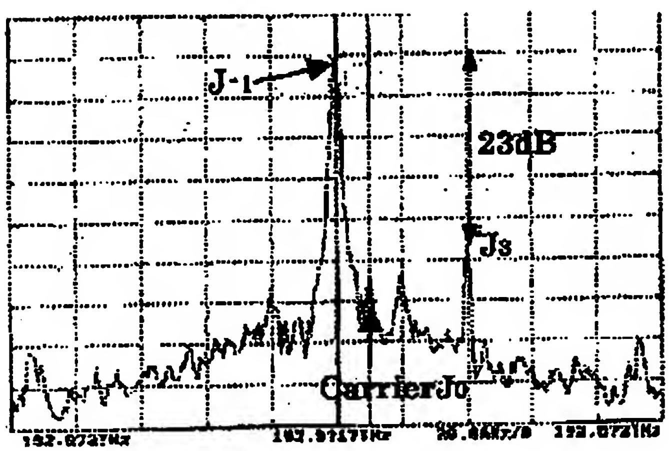
Fig. 5, Block diagram for drive circuit of a frequency shifter.

Frequency ω of the optical carrier which it inputs was approximately 192.98THz (λ ≒ 1554nm).

The output optical spectrum measured is shown in the figure 6 (a)・(b).



(a) upper sideband



(b) lower sideband

図6．10GHz単一周波に対するSSB-SC変調スペクトル(a)キャリア(b)上側波帯変調(c)下側波帯変調

Fig. 6 SSB-SC modulation spectra of 10 G bit/s mono-frequency signal. (a) carrier. (b) upper-sideband modulation. (c) lower sideband modulation.

In either upper sideband modulation or lower sideband modulation, it is easily seen that the carrier is suppressed, it has appeared in the position where peak of the primary sideband the 10GHz slips exactly from position of the input carrier.

In addition, the carrier suppressing ratio is 28dB and the sideband suppressing ratio is 23dB. Drive voltage of this time is approximately 8.0Vp-p, comparing to z-cut-LN modulator (6.2Vp-p), somewhat it was

raising, but it was large as for degree of carrier suppressing in comparison with the z-cut-LN (21dB). This is thought that for the sake of balance of the Z electric field is good. The balance depends on the MZ waveguide in comparison with the z-cut-LN. From this appraisal result, it understood that this modulator has sufficient efficiency as an optical frequency shifter

4.2 12 G b/s digital pulse patterns

We inspected next, pseud random pulse of the 12Gb/s (2^{31}-1) concerning the output optical spectrum after the SSB-SC modulating for the input of the NRZ signal. The system which is used for this measurement is shown in figure 7.

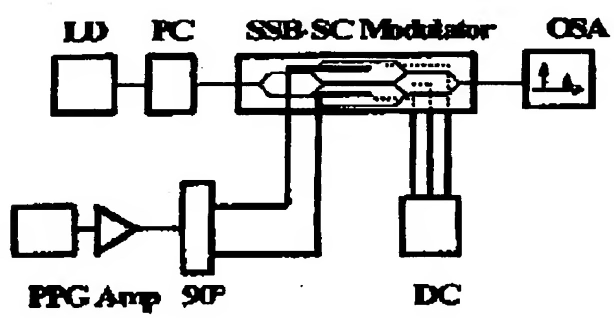


図７．デジタル信号に対するSSB-SC変調駆動系

Fig.7 Block diagram for a drive circuit of SSB-SC modulator used for a digital signal.

The 90° hybrid in the figure (Krytar corporation, 1-18Ghz), distributing input pulse in each frequency components, and the device separates the components to two of the that way component and the component which gives the phase difference of 90°.

After amplifying the digital signal which is sent from the pulse pattern generator to the 3Vp-p with the RF amplifier, it inputs into this 90° hybrid, one output is input from RFA port of the modulator, another output of from RFB port. Underneath this condition, the sideband modulation optical spectrum is shown in figure 8.

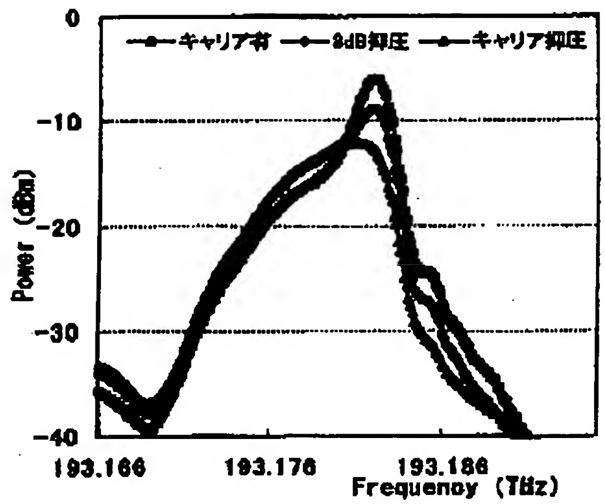


図8. 12Gbit/s デジタルパルスパタンの SSB-SC 変調スペクトル

Fig. 8 SSB-SC modulation spectra of 12 G bit/s digital pulse patterns

Looking at the figure, as understood, in comparison with former strength modulation, the occupation zone of the modulated signal decreased to approximately 60 %, and being able to control the strength of carrier light freely (in the figure, the circumstances where you could apply modulation at carrier level of 3 stages are recognized). From the result, this modulator is the device which can offer the modulation system whose frequency utilization efficiency is higher in wave length multiplex communication.

5. Application

As seen in the result of 4, when a single tone signal is input, this modulator is possible to emphasize the primary component of the optical spectrum and suppress the carrier signal and the higher order component, this modulator is possible to function as an optical frequency shifter to shift the optical frequency according to the frequency of the input signal.

Making use of this, you can think application as various optical functional devices. For example, figure 9 shows the examples when it utilizes by

combining with this modulator and the FBG, as the variable optical delay element. This comprises two circulators and the fiber Bragg grating (the FBG) and, the fiber loop (includes the SSB-SC modulator and the amplifier), and it takes a simple constitution.

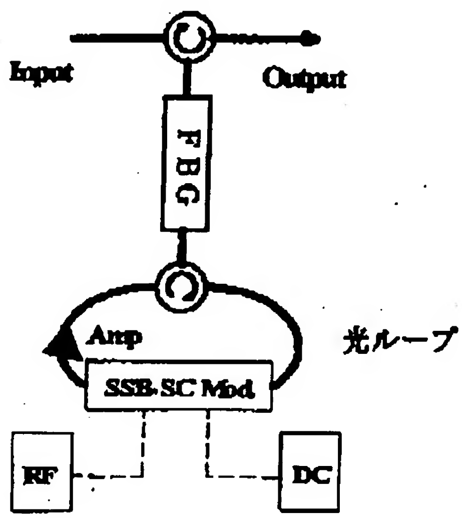


図 9. SSB-SC 変調器を用いた可変光ディレイ

Fig. 9 Variable optical delay device using SSB-SC modulator

The light which is inside of the reflected zone of the FBG is forbidden to enter into the optical loop and is output directly, on the other hand the light which is outside of the reflected zone of the FBG enters into the optical loop and is output after rounding the loop and the suffering frequency shift during the rounding by the SSB-SC modulator to be driven outside of the reflection zone of the FBG. A time delay is given during rounding the loop , that is a during suffering frequency shift. In addition, various applications are possible such as high-speed switch, and frequency standard when constructing future photonic network, and there is a possibility of being useful devices.

6. Summary

We succeeded in the simplification of drive system by producing the optical SSB-SC modulator making use of the X-cut-LN crystal. In

addition, 60% the spectrum width which information of 12 G bit/s occupies with the modulator which is reported, it can making decrease, in addition, being able to control also the strength of the carrier was shown. Furthermore, possibility of contribution to improvement of the frequency utilization efficiency in wave length multiplex communication and improvement of non-linear yield was shown. In addition, as an optical frequency shifter, it had the satisfactory efficiency of the carrier suppressing ratio 28dB, when constructing future photonic network, we showed the fact that it can become a useful device.

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